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14. ABSTRACT The standard assumption in game theory and decision theory is that the game/decision problem is, in a sense, completely understood. For example, decision problems are typically described in terms of states and outcomes, where acts are taken to be functions from states to outcomes. It is typically assumed that a decision maker (DM) knows the state space, the outcome space, and the					
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a. REPORT UU	b. ABSTRACT UU	c. THIS PAGE UU			Joseph Halpern
					19b. TELEPHONE NUMBER 607-255-9562



## Report Title

### Learning in the Presence of Unawareness: Final Report

#### ABSTRACT

The standard assumption in game theory and decision theory is that the game/decision problem is, in a sense, completely understood. For example, decision problems are typically described in terms of states and outcomes, where acts are taken to be functions from states to outcomes. It is typically assumed that a decision maker (DM) knows the state space, the outcome space, and the set of feasible acts. But this is far from clear in practice. In a complex decision problem, agents may be unaware of many relevant features, and thus unaware of possible states, outcomes, and feasible acts.

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**Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:**

**(a) Papers published in peer-reviewed journals (N/A for none)**

Received

Paper

01/20/2015	17.00	Joseph Y. Halpern, Leandro Rego. Reasoning about knowledge of unawareness revisited,, Mathematical Social Science, (05 2013): 73. doi:
01/20/2015	19.00	Joseph Y. Halpern, Rafael Pass. Conservative belief and rationality, Games and Economic Behavior, (07 2013): 186. doi:
07/24/2012	5.00	Joseph Y. Halpern, David C. Parkes. Viewpoint: Journals for Certification, Conferences for RapidDissemination, Communications of the ACM, (08 2011): 36. doi:
07/24/2012	10.00	Rafael Pass, Joseph Y. Halpern. Iterated regret minimization: a new solution concept, Games and Economic Behavior, (01 2012): 194. doi:
07/24/2012	7.00	Ian A. Kash, Joseph Y. Halpern, Eric J. Friedman.. Optimizing scrip systems: Crashes, altruists, hoarders, sybils and collusion, Distributed Computing, (12 2012): 0. doi:
07/24/2012	8.00	Peter D. Grunwald, Joseph Y. Halpern. Making decisions using sets of probabilities: updating, time consistency, and calibration, Journal of Ai Research, (11 2011): 393. doi:
07/24/2012	6.00	Leandro Rego, Joseph Y. Halpern. Generalized solution concepts in games with possibly unaware players, INTERNATIONAL Journal of Game Theory, (01 2012): 131. doi:
08/08/2012	9.00	Riccardo Pucella, Joseph Y. Halpern. Modeling adversaries in a logic for security protocol analysis, , Logical Methods in Computer Science, (01 2012): 0. doi:

**TOTAL: 8**

**Number of Papers published in peer-reviewed journals:**

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**(b) Papers published in non-peer-reviewed journals (N/A for none)**

Received

Paper

01/20/2015 18.00 Joseph Y. Halpern, Christopher Hitchcock. Compact representations of extended causal models, Cognitive Science, (08 2013): 986. doi:

**TOTAL: 1**

**Number of Papers published in non peer-reviewed journals:**

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**(c) Presentations**

Beyond Nash equilibrium: solution concepts for the 21st century, invited talk, presented at  
- C3E (Computational Cybersecurity in Compromised Environments),  
West Point, New York (Sept., 2012)  
- Distinguished Lecture Series, SUNY Stony Brook (December 2012)  
- Turing Centenary Celebration, Melbourne, Australia (Dec., 2012).  
- IIT Chennai Diamond Jubilee Celebration (Jan., 2013)

Extensive games with possibly unaware players, invited talk, presented at  
Workshop on Information Theory and Games Workshop, Santa Fe  
Institute, Sante Fe, NM (August 2012).

From qualitative to quantitative proofs of security properties  
using first-order conditional logic, invited talk, presented at  
28th Symposium on Logic in Computer Science and 26th Computer  
Security Foundations Symposium (joint invited speaker), New Orleans,  
June 2013.

**Number of Presentations: 0.00**

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**Non Peer-Reviewed Conference Proceeding publications (other than abstracts):**

Received

Paper

**TOTAL:**

**Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):**

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**Peer-Reviewed Conference Proceeding publications (other than abstracts):**

Received

Paper

- 01/20/2015 11.00 Adam Bjorndahl, Joseph Y. Halpern, Rafael Pass. Language-based games,  
Fourteenth Conference on Theoretical Aspects of Rationality and Knowledge. , . : ,
- 01/20/2015 16.00 Ittai Abraham, Danny Dolev, Joseph Y. Halpern. Distributed protocols for leader election: a game-  
theoretic perspective,  
7th International Symposium on Distributed Computing. , . : ,
- 01/20/2015 15.00 Brad Gulko, Samantha Leung. Maximin Safety: When Failing to Lose is Preferable to Trying to Win,  
12th European Conference on Symbolic and Quantitative Approaches to Reasoning with Uncertain. , . : ,
- 01/20/2015 14.00 Joseph Y. Halpern. Weighted regret-based likelihood: a new approach to describing uncertainty,  
12th European Conference on Symbolic and Quantitative Approaches to Reasoning with Uncertain. , . : ,
- 01/20/2015 13.00 Nan Rong, Joseph Y. Halpern. Towards a deeper understanding of cooperative equilibrium:  
characterization and complexity,  
11th International Joint Conference on Autonomous Agents and Multiagent Systems. , . : ,
- 01/20/2015 12.00 Joseph Y. Halpern, Rafael Pass. Game theory with translucent players,  
Fourteenth Conference on Theoretical Aspects of Rationality and Knowledge. , . : ,
- 07/21/2012 3.00 Joseph Y. Halpern, Samantha Leung. Weighted Sets of Probabilities and Minimax Weighted  
Expected Regret: New Approaches for Representing Uncertainty and Making Decisions,  
Twenty-Seventh Conference on Uncertainty in AI (UAI '2012). 15-AUG-12, . : ,
- 07/21/2012 2.00 Joseph Y. Halpern, Willemien Kets. Ambiguous Language and Differences in Beliefs},  
Thirteenth International Conference on Principles of Knowledge Representation and Reasoning  
(KR2012). 10-JUN-12, . : ,
- 07/21/2012 1.00 Danny Dolev, Dror G. Feitelson, Joseph Y. Halpern, Raz Kupferman, Nati Linial. No Justified Complaints:  
On Fair Sharing of Multiple Resources,  
3rd Conference on Innovations in Theoretical Computer Science (ITCS 2012). 08-JAN-12, . : ,
- 07/21/2012 4.00 Joseph Y. Halpern, Rafael Pass, Lior Seeman. I'm Doing as Well as I Can: Modeling People as Rational  
Finite Automata,  
Twenty-Sixth AAAI Conference on Artificial Intelligence (AAAI-12). 24-JUL-12, . : ,

**TOTAL: 10**

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

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(d) Manuscripts

Received      Paper

TOTAL:

Number of Manuscripts:

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Books

Received      Book

TOTAL:

Received      Book Chapter

TOTAL:

Patents Submitted

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Patents Awarded

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Awards

``Language-based games" selected as one of two papers from  
TARK (Conference on Theoretical Aspects of Reasoning About Knowledge) to  
be presented at session at IJCAI 2013 on best papers from related conferences.

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### Graduate Students

<u>NAME</u>	<u>PERCENT SUPPORTED</u>	Discipline
Adam Bjorndahl	0.26	
Samantha Leung	0.39	
Nan Rong	0.08	
Lior Seeman	0.38	
<b>FTE Equivalent:</b>	<b>1.11</b>	
<b>Total Number:</b>	<b>4</b>	

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### Names of Post Doctorates

<u>NAME</u>	<u>PERCENT SUPPORTED</u>
<b>FTE Equivalent:</b>	
<b>Total Number:</b>	

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### Names of Faculty Supported

<u>NAME</u>	<u>PERCENT SUPPORTED</u>	National Academy Member
Joseph Halpern	0.17	
<b>FTE Equivalent:</b>	<b>0.17</b>	
<b>Total Number:</b>	<b>1</b>	

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### Names of Under Graduate students supported

<u>NAME</u>	<u>PERCENT SUPPORTED</u>
<b>FTE Equivalent:</b>	
<b>Total Number:</b>	

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### Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: ..... 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:..... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:..... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):..... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:..... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense ..... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:..... 0.00

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### Names of Personnel receiving masters degrees

<u>NAME</u>
Adam Bjorndahl
Samantha Leung
<b>Total Number:</b>

**Names of personnel receiving PhDs**

<u>NAME</u> Adam Bjorndahl <b>Total Number:</b>	<b>1</b>
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**Names of other research staff**

<u>NAME</u>  <b>FTE Equivalent:</b> <b>Total Number:</b>	<u>PERCENT SUPPORTED</u>
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**Sub Contractors (DD882)**

**Inventions (DD882)**



## Scientific Progress

The ultimate goal of this project is learning in the presence of unawareness. In this reporting period, I am my student Samantha Leung continued continued work on a novel approach to representing and reasoning about the type of uncertainty that will typically arise when learning in the presence of unawareness. Typically uncertainty is represented by a single probability measure. But this does not seem appropriate if the agent has just learned about some new concepts of which she was not previously aware. In the absence of reliable experience with these new concepts, it seems unreasonable to expect the agent to be able to describe a single distribution to represent her uncertainty. It is perhaps more plausible that there should be a set of distributions. But then how should decisions be made using this set of distributions? And how should the set be updated in light of new information?

To understand the problem, suppose that the agent is initially uncertain about the bias of a coin (so that the probability of heads could be anywhere between, say,  $1/3$  and  $2/3$ ). This uncertainty can be represented in the obvious way by a set of distributions. But now suppose that the agent tosses the coin repeatedly, observing that roughly  $1/3$  of the coin tosses are heads. This should make the measures that assign a probability significantly different from  $1/3$  to heads more and more unlikely. We thus put weights on these measures, ranging from 0 to 1; roughly speaking, the weight of a measure can be viewed as measuring how likely that measure is to be the true measure. We then defined a notion of regret with respect to these weighted measures. As we showed, this approach is psychologically plausible, converges to expected utility maximization in the limit, as more information is learned, handles unawareness, and has an elegant axiomatization. In this reporting period, we considered a notion of likelihood determined by this approach to decision making; in addition, we focused on the dynamic problem: how should decision be made using this approach over time. It turns out that, in this case, a key question is what the menu of alternative should be. Should forgone opportunities, ones that are no longer options given previous decisions, be taken into account when computing regret? While it has been argued that a rational person should just look forward, and not take into account actions that cannot be undone, it is clearer that people do take into account foregone opportunities when computing regret. Moreover, it turns out that doing so allows us to avoid some standard anomalies in decision making (like endless procrastination).

In other work, Rafael Pass, Adam Bjorndahl (my Ph.D. student), and I considered what we called language-based games, in which utility is defined over descriptions in a given language.

By choosing the right language, we can capture psychological games (where an agent's utility may depend, for example, on his beliefs regarding others and expectations) and reference-dependent preference (where utilities can depend for example, on how the price of an object compares to a reference point). Of special interest to us are languages that can express only coarse beliefs (e.g., the

probability of an event is "high" or "low", rather than "the

probability is .628"): by assuming that a player's

preferences depend only on what is true in a coarse language,

we can resolve a number of well-known paradoxes in the literature, including the Allais paradox. Despite the expressive power of this approach, we show that it can describe games

in a simple, natural way. Nash equilibrium and rationalizability are

generalized to this setting; Nash equilibrium is shown not to exist in

general, while the existence of rationalizable strategies is proved

under mild conditions on the language. This line of research is relevant to the overall goal of the project since one important question of interest is dealing with the case where the language talks about awareness.

## Technology Transfer